

High-brightness Liquid-jet Laser-plasma Enabling 10-second-exposure Water-window Cryo Microscopy

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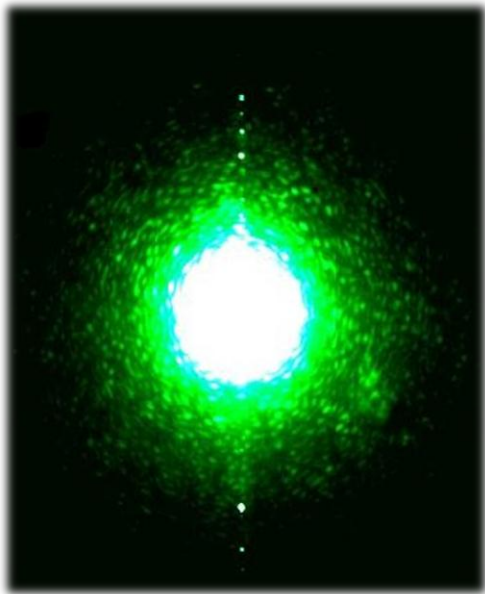
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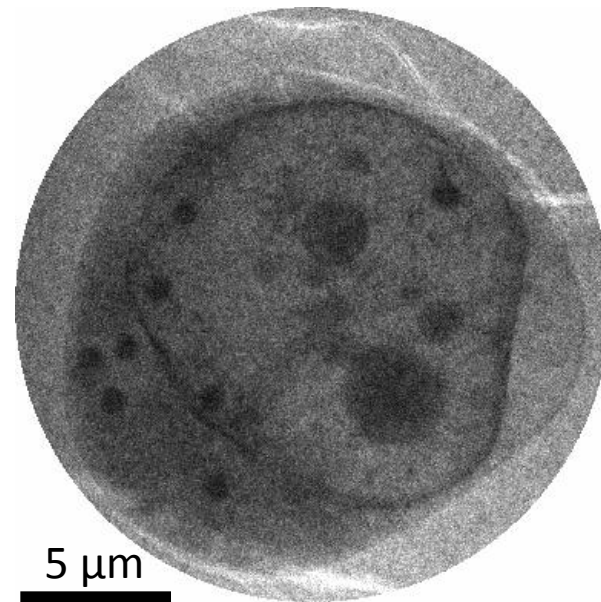
³*TU – Technische Universität Berlin, Berlin*

Main results

Bright laboratory soft x-ray source

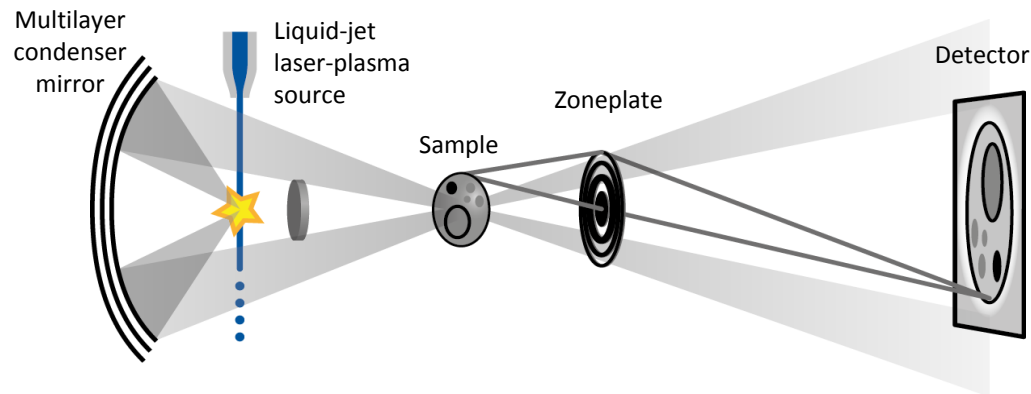
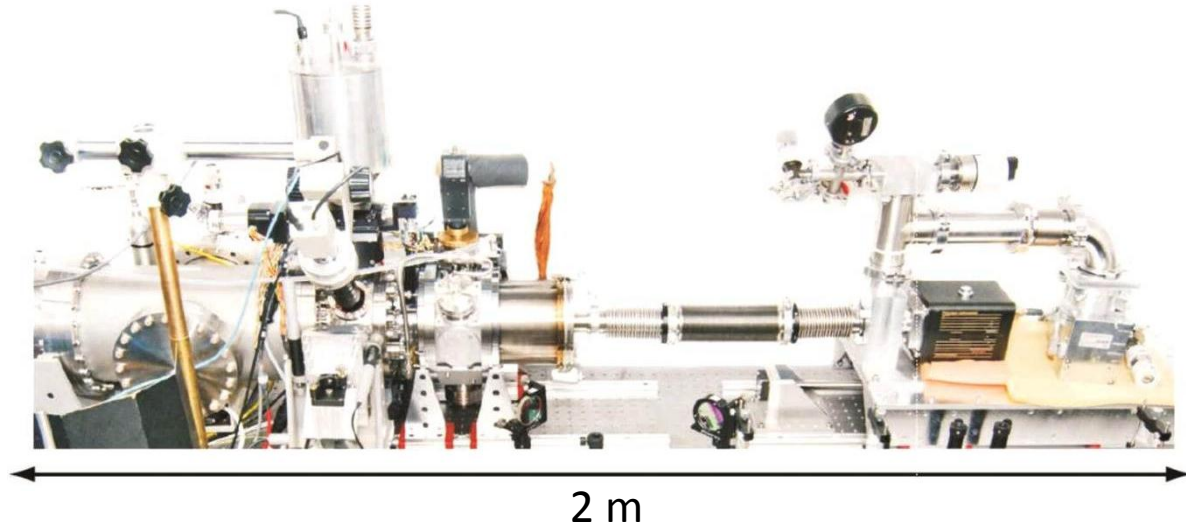


Short exposure time imaging

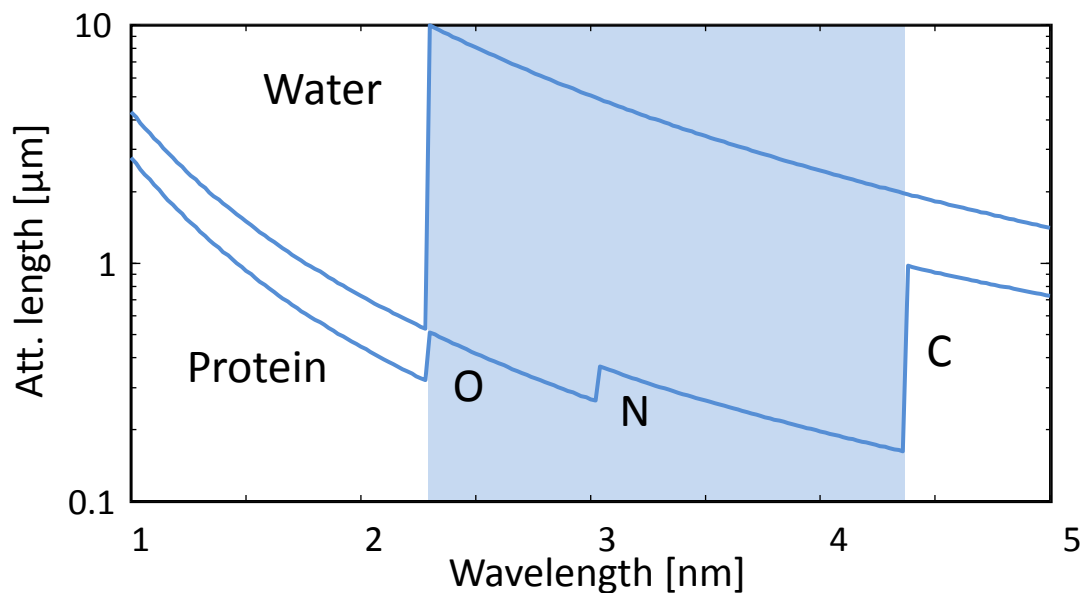


Aquisition time: 10 s

Stockholm X-ray Microscope

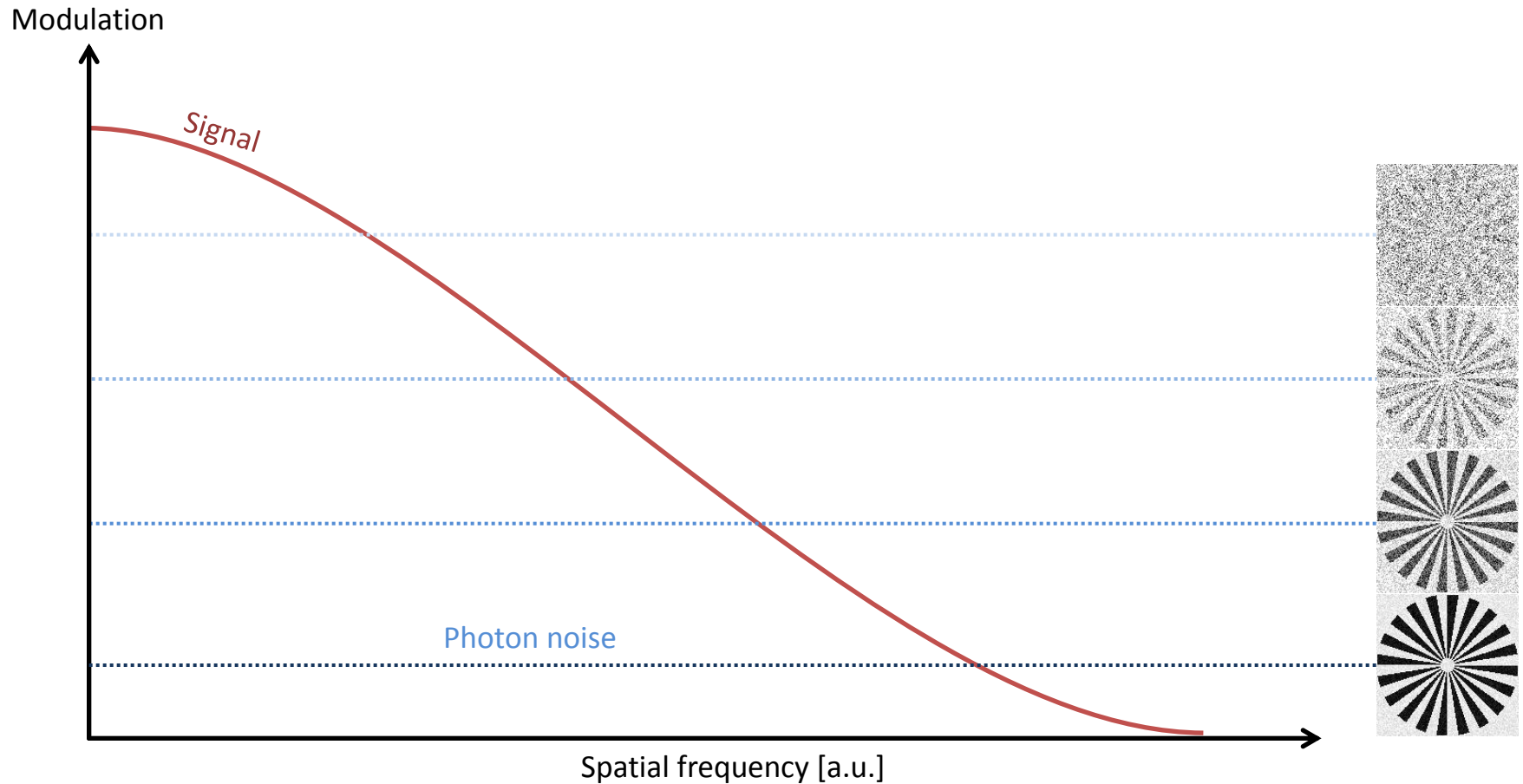


Water-window



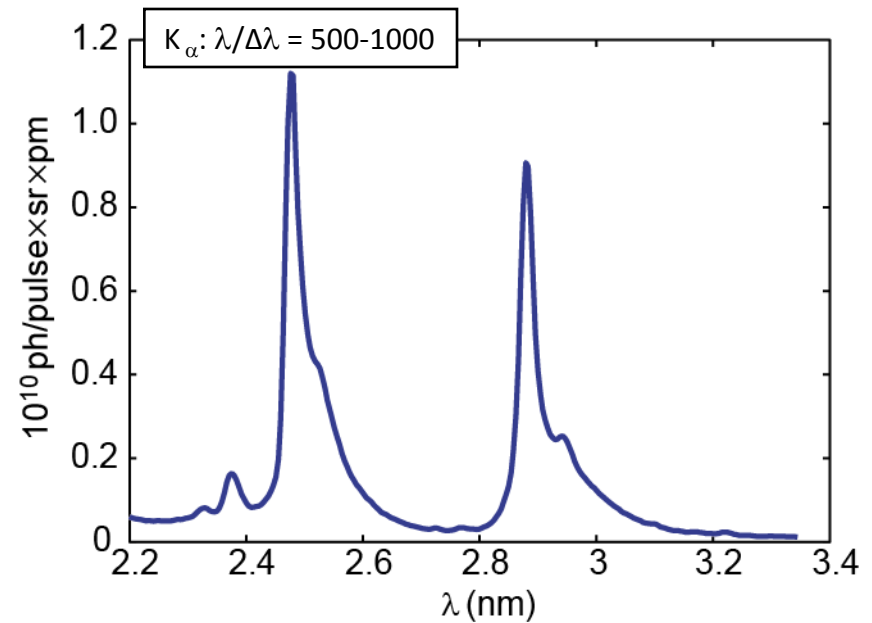
- + **Resolution:** $0.61\lambda/NA$
- + **Contrast:** Absorption water \ll absorption protein
- + Possibility to study thick ($\sim 10 \mu\text{m}$) objects
- Lack of laboratory high-brightness sources

SNR – Signal to noise ratio



Source

Measured spectrum from source



D. H. Martz et al, Opt. Lett. (accepted)

Jet

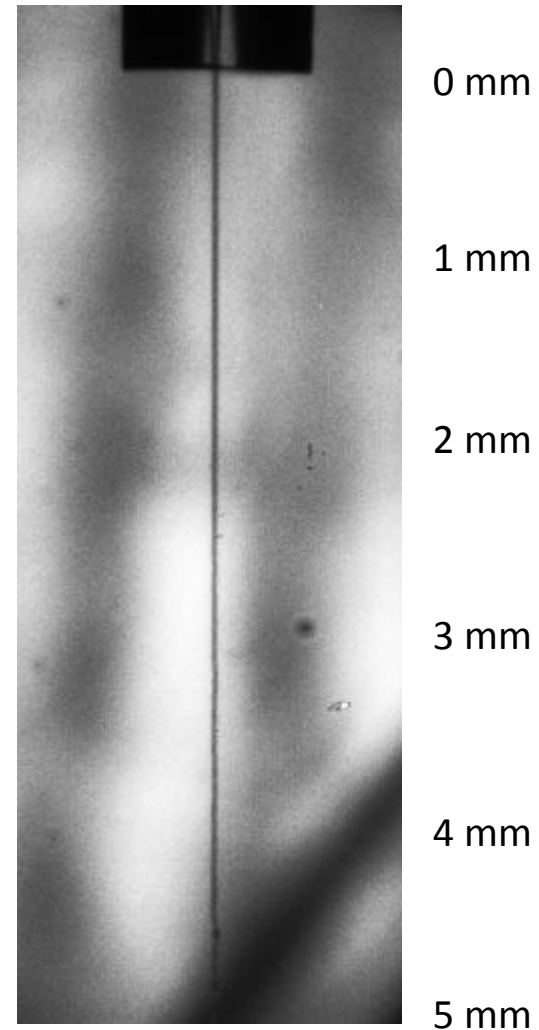
Regenerative target

Backing pressure: ~ 20 bar

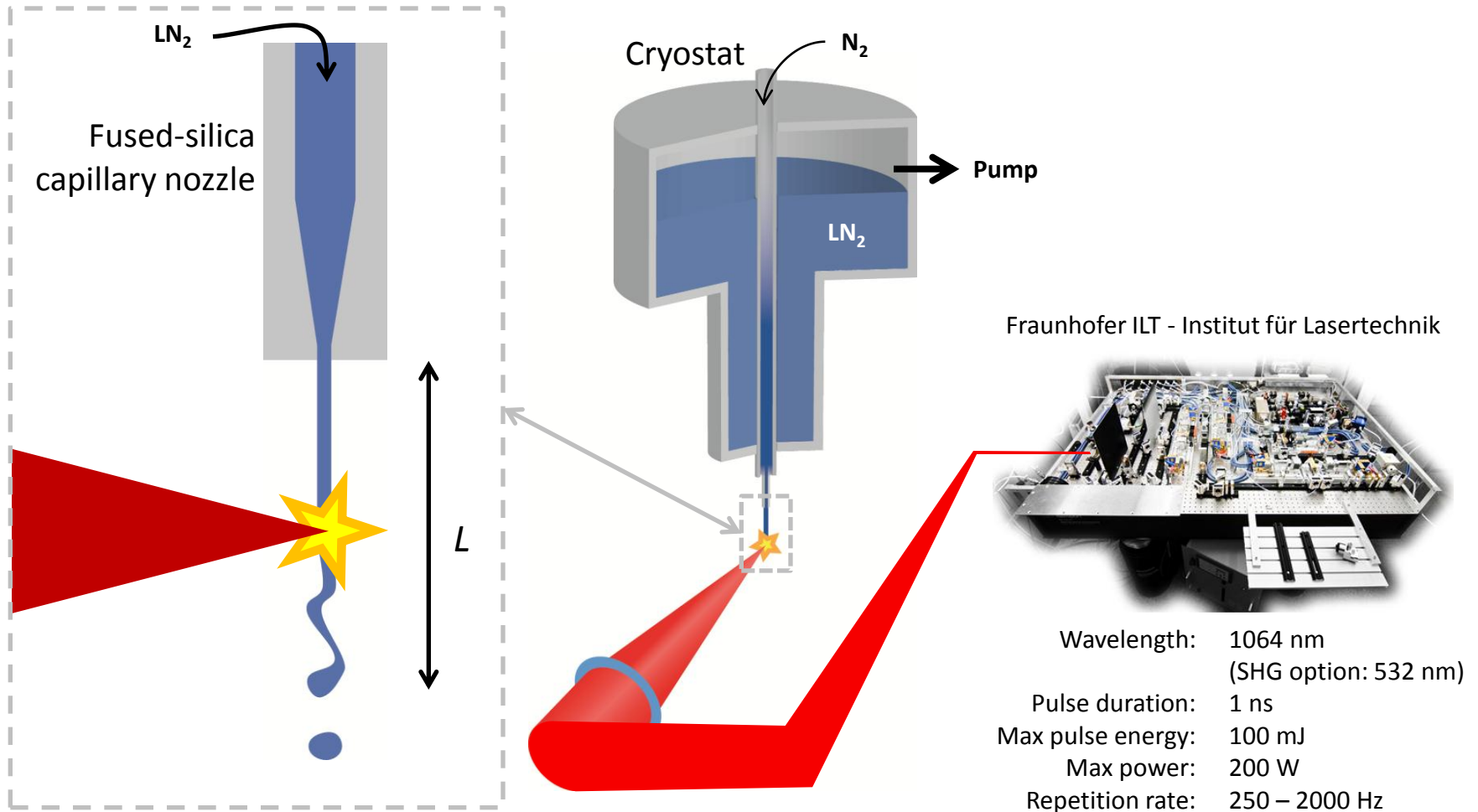
→ Jet speed: ~ 50 m/s

Tapering optimized to avoid turbulence.

Breakup length: 3-5 mm →



Jet delivery system & Laser



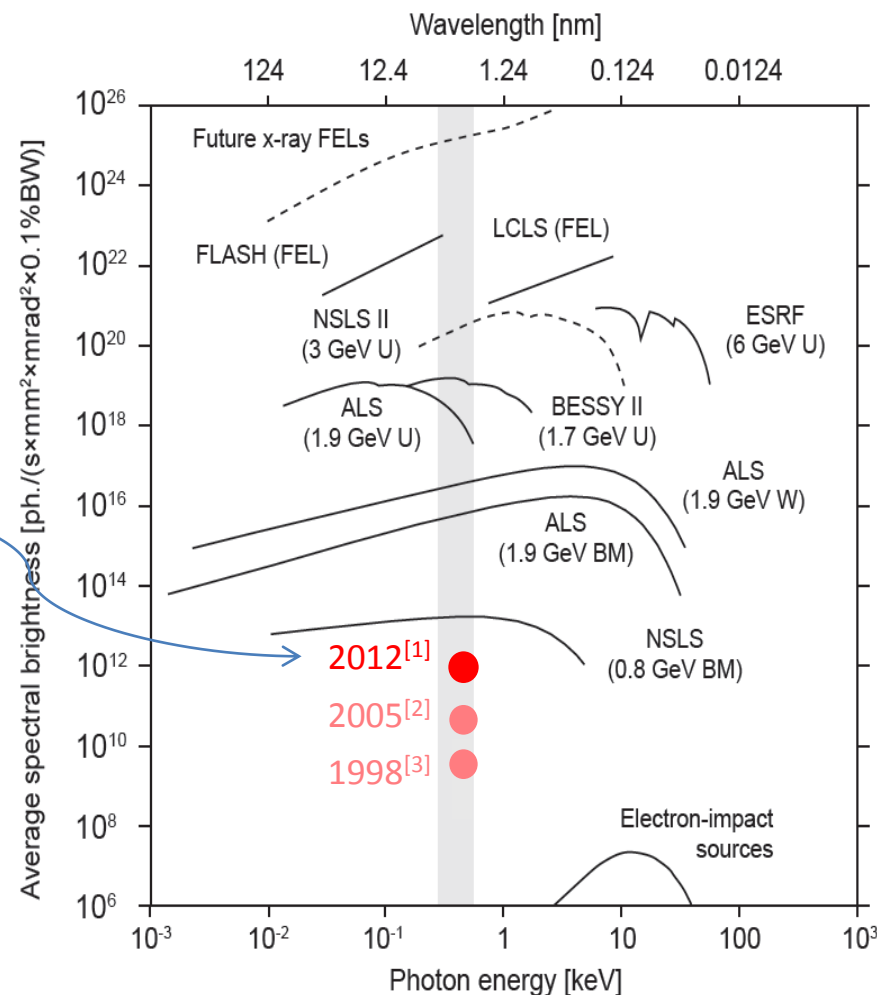
Brightness

$$1.5 \times 10^{12}$$

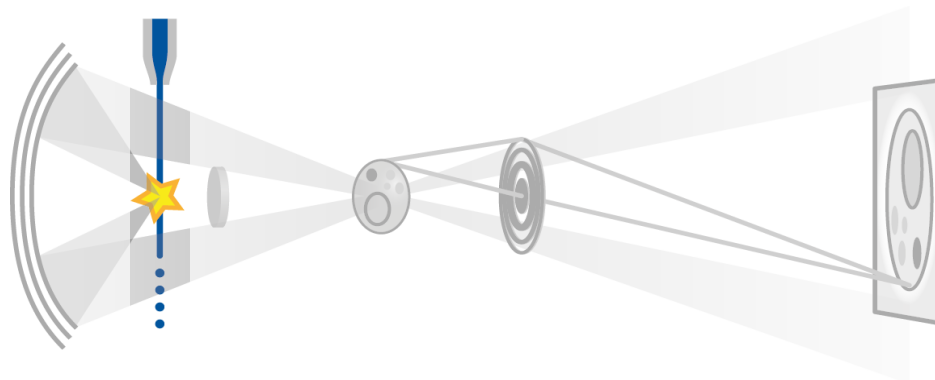
photons /
(s × mm² × mrad² × line)

$$\lambda/\Delta\lambda = 500-1000$$

- [1] D. H. Martz et al, *Opt. Lett.* (accepted)
 [2] P. A. C. Jansson et al, *Rev. Sci. Instrum.* (2005)
 [3] M. Berglund et al, *Rev. Sci. Instrum.* (1998)

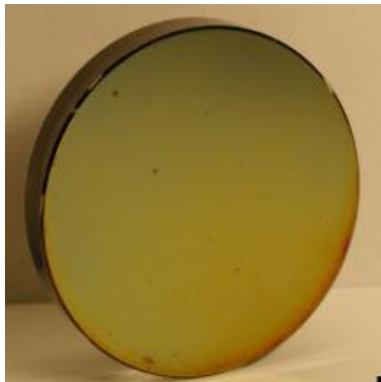


Microscope



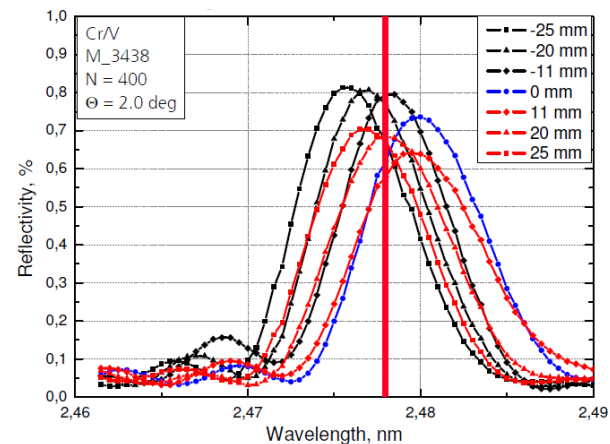
Multilayer condenser mirror

Cr/V - Multilayer

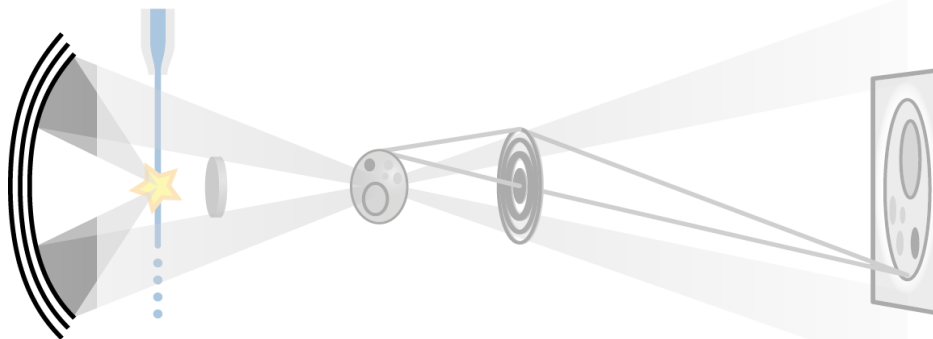


- Ø 58 mm
- 350 mm radius of curvature
- 200 bilayers
- $\lambda/\Delta\lambda \approx 300$
- Good uniformity
- Good λ match

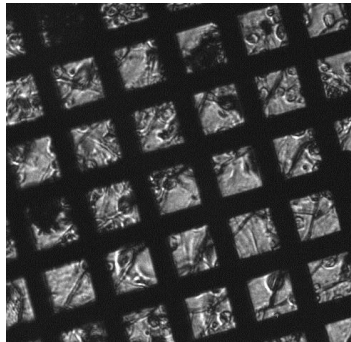
- Reflectivity: $\sim 0.6\%$



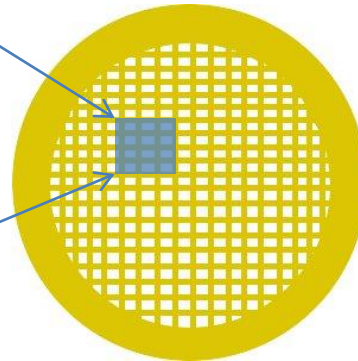
Thanks to S. Yulin, FhG Jena



Sample



Standard TEM-grids

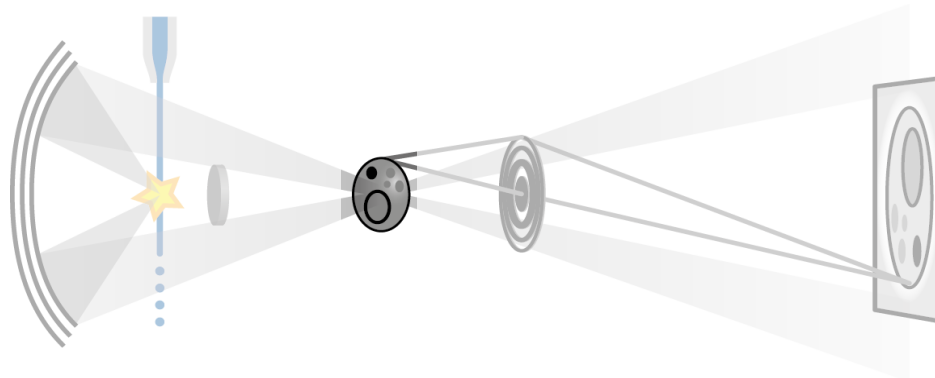


Standard TEM-sample holder

Cryo:

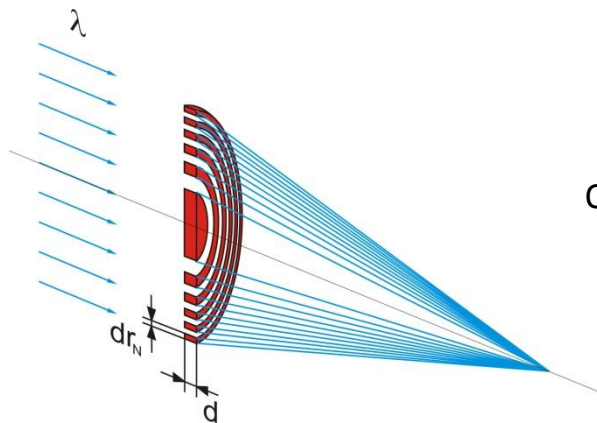
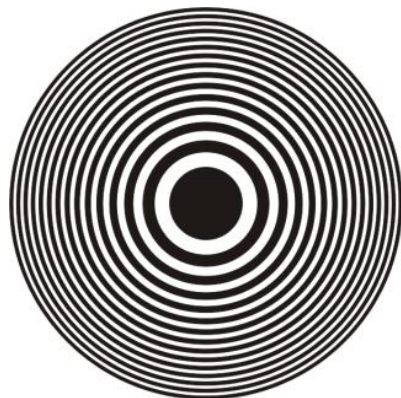


Non-cryo:



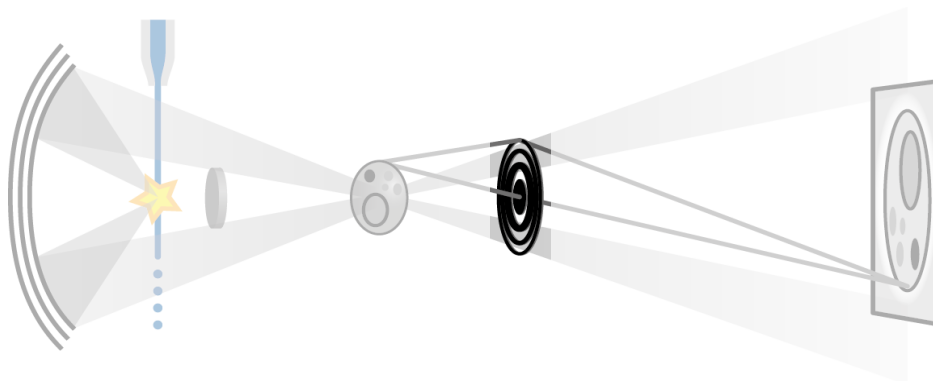
Zone plate

Circular diffraction gratings



$$\Delta r_{Rayl.} = 1.22 dr_N$$

Material: Nickel
Diameter: 50 – 100 μm
Outermost zone width: 25 – 50 nm
Diffraction efficiency: ~7-8 %
(1st order)

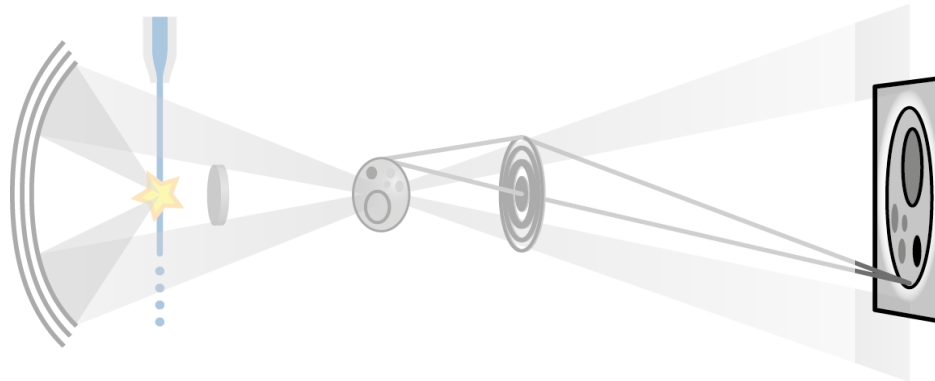


Detector

PI-SX – Princeton Instruments



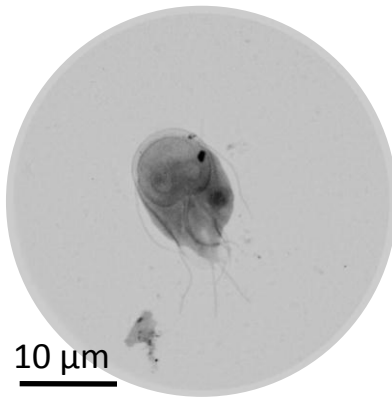
- Cooled (-30°C) CCD
- 2048×2048 px, $13.5 \times 13.5 \mu\text{m}^2$
- Quantum efficiency: $\sim 60\%$
- AD-converter: 16 bit



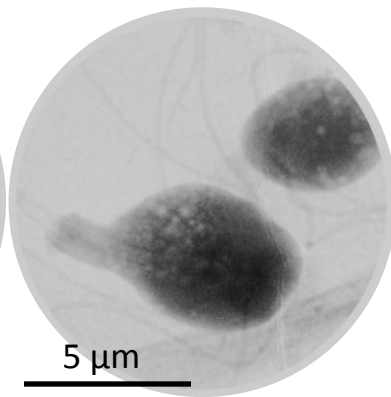
Cryo microscopy (old system)

Parasites

Giardia intestinalis



Spironucleus salmonicida



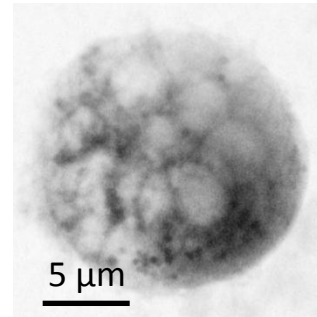
- 5-10 min exposure time / image

H.M. Hertz et al, J. Struct. Biol. (2012)

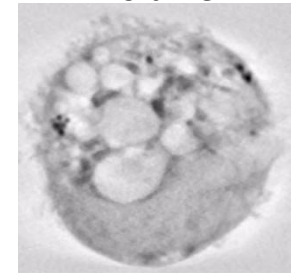
Tomography

Human kidney cell

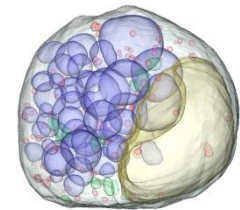
2D image



Reconstructed volume



Surface rendering

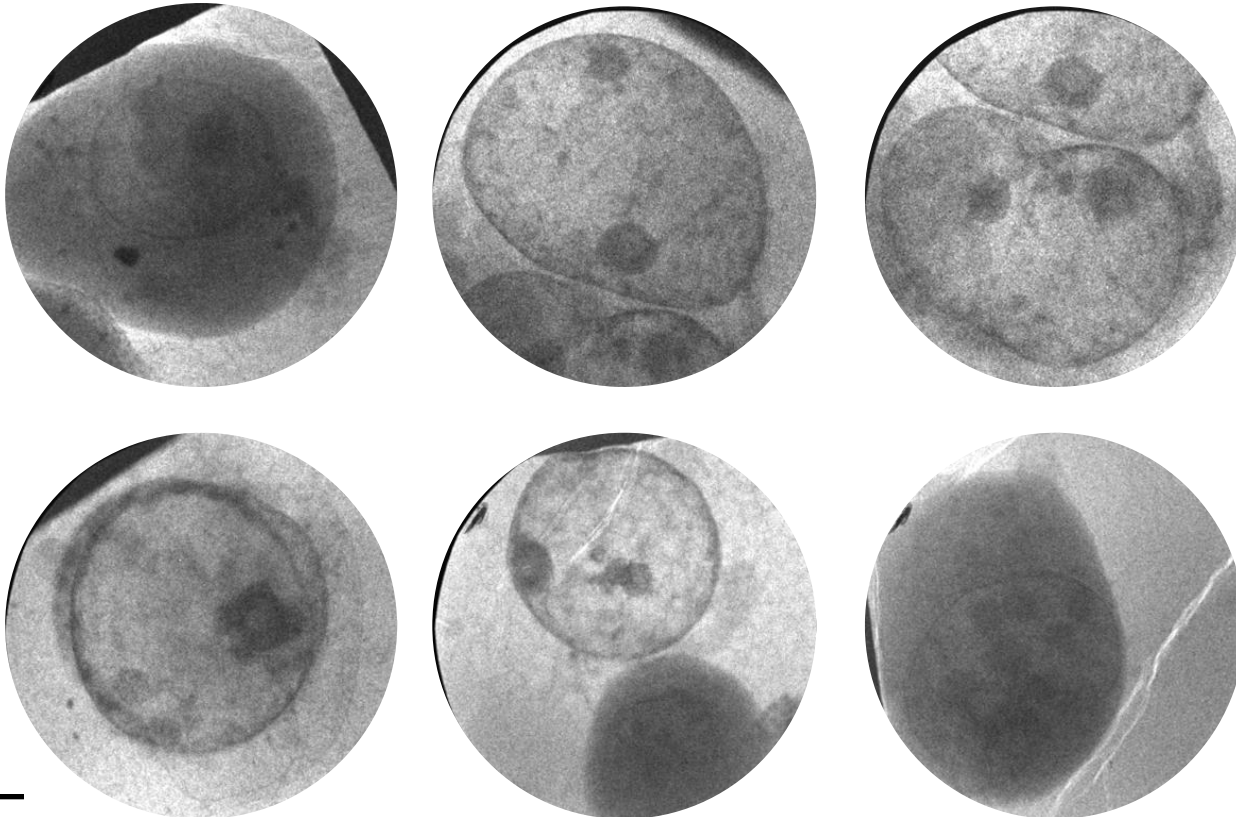


- 58×120 s
- 1.5° tilt increments

M. Bertilson, et al, Opt. Lett. (2011)

Short exposure times

Human immune system B-cells - 10 seconds exposure images



Summary

- Highest-average-brightness laboratory source operating in the water-window demonstrated
- Short exposure times, approaching that of microscopes based on early synchrotron sources